Title:

From simple prescriptive to complex descriptive models: an example from a recent command decision experiment.

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Final paper for:

2003 8th International Command and Control Research & Technology Symposium

National Defense University, Washington. 17-19 June 2003.

Submitted to Track: **C2 Decision-making and Cognitive Analysis.**

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **From simple prescriptive to complex descriptive models: an example from a recent command decision experiment**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **QinetiQ,Room 22 Turing Building,St Andrews Road,Malvern WR14 3PS, UK, ,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**40**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

From simple prescriptive to complex descriptive models: an example from a recent command decision experiment.

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Abstract

Recent research into command modeling has allowed us to build theoretical utility-based representations of the three layers: physical, information and cognitive (see Figure 1) to give models that transform observable data through interpretive indicators and onto course of action assessment. The key transfer function is driven by (a minimum of) two parameters and the function changes its shape (and influence) as the decision-maker's context changes (for example, as local decisions become more global in their potential impact) [1]. The paper explores the applicability of the theory using results of a recent BG command decision-making experiment. The experimental results show that splitting factors can be derived from the subjective nature of the situation assessment, and the personality, training experience and history of the decision-maker need to be taken into account.

The paper recommends that in order to capture these deeper aspects of the human decision-making process, there is a need to:

- Define a landscape whose contours are defined by the subjective context
- Evaluate costs of moving over the landscape
- Overlay opponents' current positions and intents.

The landscapes are wholly subjective and will change as the decision-maker's "world" changes over time. The example will illustrate these points showing that the move towards complex, less prescriptive C2 models will increase the need for more subjective C2 experimentation**.** The challenge then is how to capture this deeper representation of human decision making in a way that is useful for quantitative modeling.

Introduction

A new approach to the representation of Command and Control in fast running, high level constructive simulation models has been developed [2], and is currently being incorporated into a new generation of simulation models with Command and Control at their core. As part of this set of ideas, the Rapid Planning approach has been developed,

[*] This work has been carried out under funding from Corporate Research Programme TG11 (C2 in OA models), D S&A (P&P) Ministry of Defence, Whitehall, London UK. Experimental work was carried out under TG5: Contribution of the Human Element to Command Effectiveness.

which represents the decision-making process of experts under stress, working in fast and fluid circumstances. Rapid Planning uses sets of Dynamic Linear Models (DLM) [2], to capture the process of pattern matching which lies at the heart of the approach. This quantitiative representation is Bayesian in nature and is driven by incoming information. This Bayesian model has been extended to include a further set of factors that drive the command decision process [1,3,4] based on non-linear utility theory as developed originally by Professor Jim Smith [5,6,7].

The underlying theory makes three assumptions about the military C2 decision process:

- there is uncertainty in belief about future outcomes;
- losses may result from any decision (or lack of decision);
- the overall desire is to minimise expected loss (or maximise potential gain/utility).

Belief in outcome can be represented by a probability distribution function (e.g log-Normal) and the uncertainty measure is the width (coefficient of variation) of that belief function. The perceived loss is generally a bounded, U-shaped function of actual outcome, whose minimum is at the point of desired (or planned) end-state. It is assumed that the shape of this function changes as the degree of responsibility or importance placed on the decision-making HQ to "get-it-right" changes. (Utility is used to develop the theory and may be used rather than loss but it should be noted that the relationship between loss and utility is generally not strictly reciprocal.) The two functions combine to give an expected loss function and when this is minimised a cusp catastrophe decision surface emerges. This extension into discontinuous command agent models moves us some way towards descriptive models; however, we needed experimental data to establish the relationships between utility/loss, uncertainty, beliefs, constraint formulation, etc. and their effects on the selection of Course of Action (CoA).

One part of a UK experimental programme to investigate the "Contribution of the Human Element to Command Effectiveness" used a Recognition-Primed Decision-making (RPD) experimental game to examine the hypothesis that CoA selection is a direct consequence of pattern matching. RPD was developed by Klein [8] to describe how experienced practitioners make decisions in their domain of expertise. It consists of three phases: situation recognition, serial course of action evaluation and mental simulation. Situation recognition in the presence of plausible goals leads to the selection of appropriate action given a minimum or no search through alternatives. Serial course of action evaluation is undertaken only if the first course of action is rejected. Mental simulation is the process used to serially evaluate actions if course of action evaluation is necessary.

A key feature of the RPD model is the idea that decision makers do not assess a situation using the information presented to them. Rather, they recognise the situation by matching the pattern of cues and indicators, contained in presented information, to previous situations remembered from past experience (either actual or simulated through training). This recognition process provides access to pre-learned knowledge about how to behave and what to expect in such a situation. This pre-learned knowledge shapes the way the decision-maker perceives the situation presented and provides the starting point for course of action generation.

Another key feature of RPD is the re-enforcement of the idea that decision-makers do not consider all possible courses of action in parallel, but rather consider each in turn and fix

upon the first satisfying course. In time-pressured situations, it seems likely that the criteria for declaring an option ‘satisfying’ may be influenced by the lack of time to consider further courses. This implies that courses of action conceived early in the assessment process will tend to dominate, i.e. that knowledge about what to do in a given type of situation derived from experience will dominate over action knowledge developed during situation assessment.

The RPD game was designed to measure the predisposition of participants, in a situation in which they should be experts, by requiring them to make a rapid determination of a course of action in the face of an ambiguous tactical picture. The game form was originally created for experimental work with Naval Principal Warfare Officers, in which there was a wide diversity of action responses and weak statistical relationship with CoA chosen in a normal, real time wargame of a similar situation [9]. In the present research, the RPD game form was used with Army officers playing the part of Battlegroups commanders and their staff. [10]

The RPD games involved presenting participants, in a 'classroom' format, with an initial operational picture and situation brief. Once participants had time to assess the situation (about 10 minutes), an intelligence report was provided which may or may not represent a significant change demanding action. The participants were then asked to choose and write down a course of action without being given time to think about it. The ambiguity of the intelligence update was designed to give them some room for choosing different courses of action so that their pre-dispositions were allowed to surface as variations in choice.
After the course of action was selected, participants were invited to record their situation assessment and the key indicators considered relevant to their course of action choice. It was accepted that this data may reflect post-hoc rationalisation to some extent. To account for any changes in situation assessment due to the process of having to express it, the participants were also offered the opportunity to nominate a different course of action "having thought a little more about the situation" and to record any other courses of action that may be considered.

The results of the RPD game provide a set of data useful for development of potentially more descriptive Command Agent models (see Figure 2).

The RPD experimental game results give us a context within which to define the utility (or loss) values, the constraint “landscape” and the beliefs about future outcome, all of which are subjective. Indeed, it appears that the extent to which each is considered in the pattern-matching process determines the CoA selection. This apparent branching structure seems to account for the grouping according to selected CoAs across the twenty-four experienced military subjects taking part in the RPD game.

The RPD Game is based around command decisions at Battle Group (BG) level set in two different conflict scenarios: warfighting and peace support.

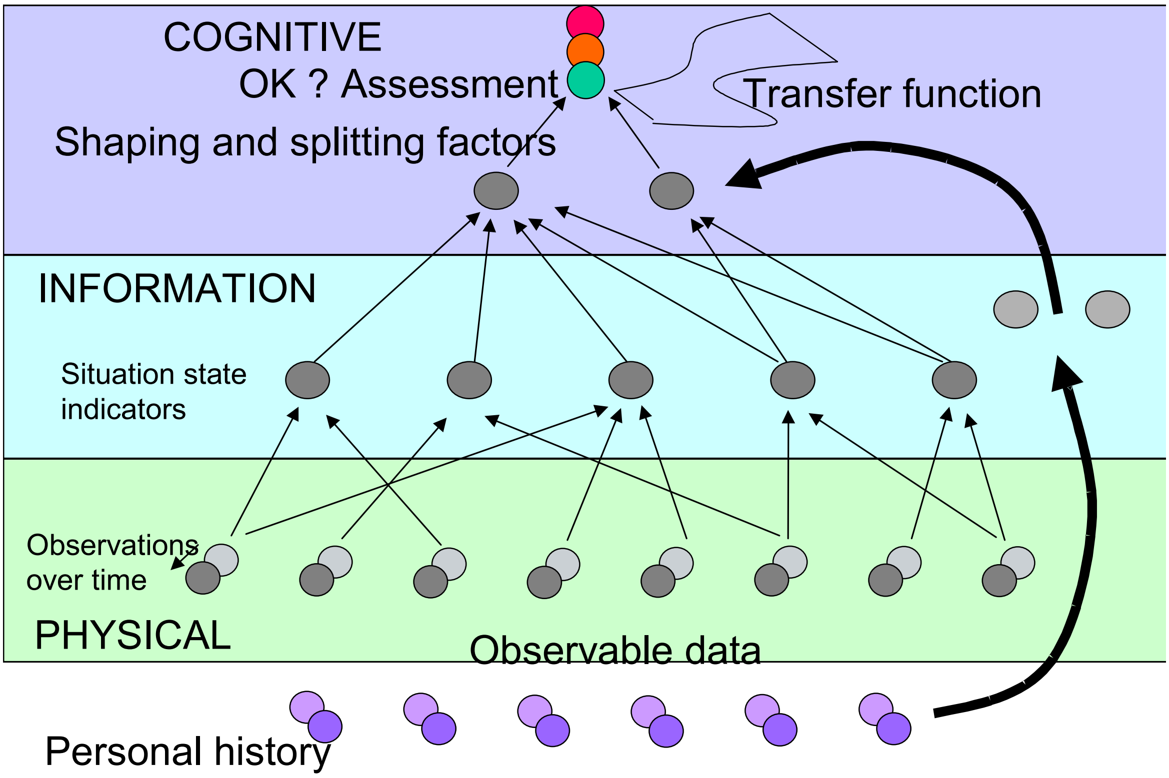


Figure 1: Cognitive Layer Extension to Bayesian Command Agent models

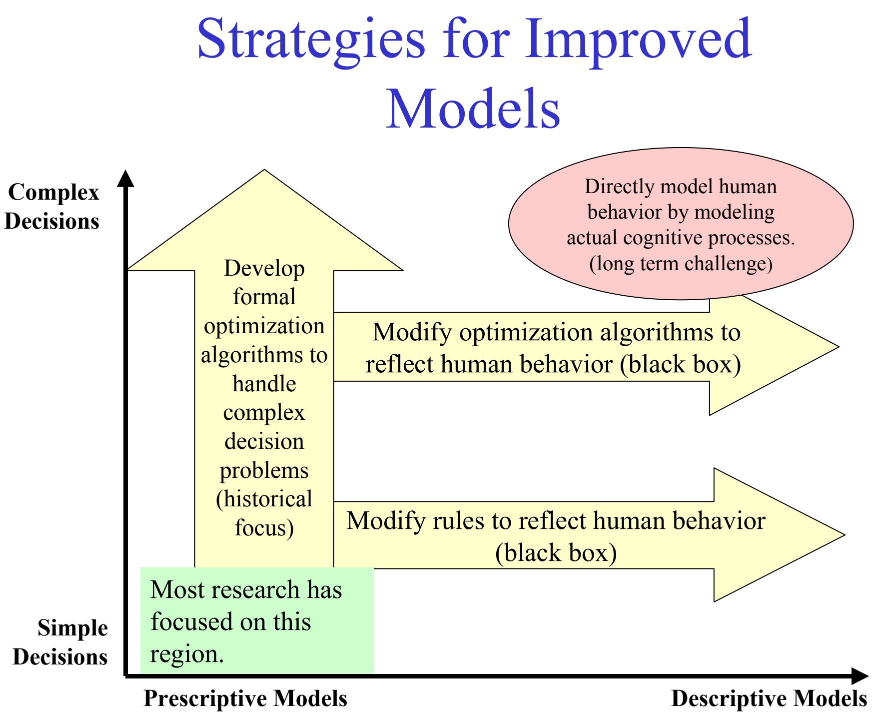


Figure 2: Aim for command agent models is complex descriptive

BG Command Decision-making experiment

Scenario 1: warfighting

This game was played after participants had taken part in a Brigade level planning exercise, which provided them with situation immersion and a context for the RPD game. In the RPD warfighting game the twenty-four participants played individually and were focussed on the BG formed by the Queens Royal Hussars (QRH) located on the Elfas feature (top left in Figure 3). The Brigade mission was to delay the enemy advance for 24 hours until bridges to the West could be secured. The following written brief was presented to the teams:

Unit	Activity	CE
SCOTS DG	Holding	85%
D&D	Holding	85%
QRH	Advancing	95%
2 RGJ	Re-deploying	75%
AH Sqn	-	100%
1/179 Tk Bn	Defending	20%
1/179 MR Bn	Defending	25%
179 Sep Atk Bn	Defending	20%
2/179 Tk Bn	Advancing	90%
2/179 MR Bn	Advancing	85%
3/179 MR Bn	Assembly Area	100%
179 Sep Lt MR Bn	Assembly Area	100%
179 Arty Regt	Holding	85%

Time: 2115 hours	
SCOTS DG, D&D are reconstituting.. QRH (3,0) remain in hides on the south-eastern part of the Elfas feature. 2 RGJ (2,2) Armd Sqn south of Rotenkirchen is re-deploying north-west through the Ahlsburg feature towards Dassensen. Red 2nd Ech began to deploy at 2000 hours with 2/179 Tk Bn in the north, following the B3 around Einbeck and then the K658/B64. In the south, the 2/179 MR Bn followed an axis Edemissen – Wellersen – Ellensen – Luthorst. Probable elements of a BAG have been detected SE of Lauenberg. At 2040 hours, one dismounted infantry Coy, probably from the Sep Lt Mr Bn, has been lifted by hel to Vorwohle. 2 Tk Bn recce has reached area of Vorwohle linking with the Coy lifted by hel. Recce is also in the area of Avendshausen and Voldagsen. Lead elements of the Bn have passed through Eimen with the remainder of the Bn stretched out on an axis Eimen - Wenzen (route K658) to the outskirts of Einbeck. 2 MR Bn recce has reached the Wangelnstedt - Luthorst gap. Lead elements have reached the southern outskirts of Luthorst. The remainder of the Bn is following an axis Erichsburg – Ellensen – Wellersen - (area north of) Dassensen. Lead elements were engaged by blue arty reducing the fwd Coy to Pl str.	
Weather: Dry with low lying mist in lower river valleys	
6 hour forecast: Dry with mist lifting by 0800 hours	
Moon state: 90%	
Sunrise: 6:47	Sunset: 16:55

The following update was presented and the subjects were asked to write down immediately their CoA:
At 2105 hours, reporting indicated probable troop deployment by helicopter to West of Elfas feature. The strength of these deployments is not known but is assessed as Coy(+).

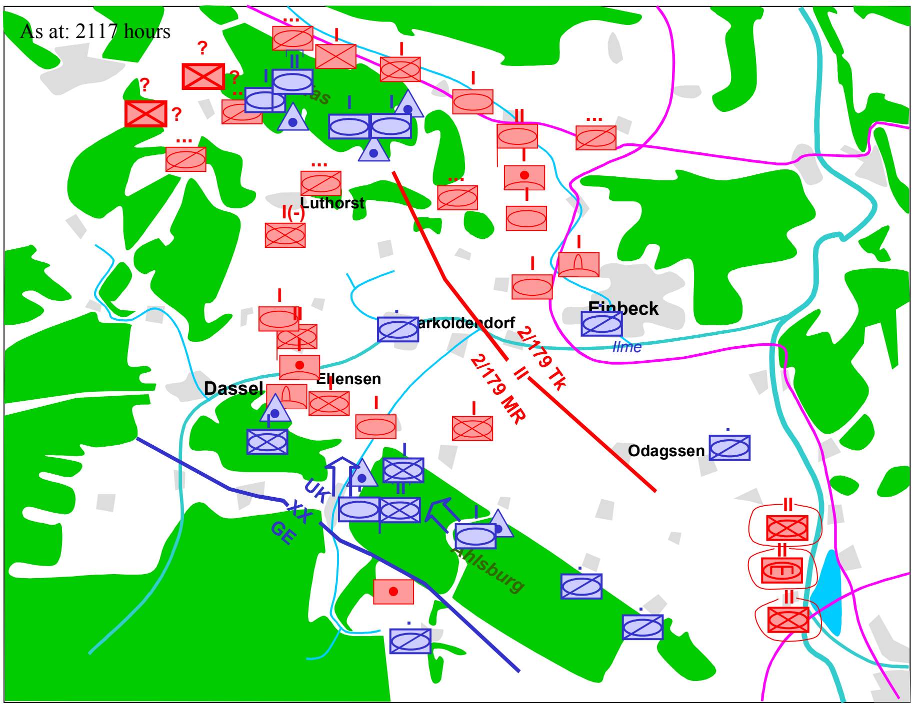


Figure 3: Warfighting scenario situation update

The subjects' responses varied across a wide range of courses of action: attack north, attack east, attack west, do nothing and remain hidden, do nothing but send situation report to Brigade and request more information, act as eyes-on for Brigade artillery, etc.

Scenario 2: peace support
The peace support RPD game was not related to any previous planning exercise, so a higher level background brief was provided to allow the participants to be immersed in the overall situation.

Background
The scenario is set in the former Central European 'Livnovian Federation'. This consisted of Livnovia, Gorligia, and Slokas. Following the break-up of the Federation, the two major entities, Gorligia and Livnovia have been left in a state of an armed stand-off.

The ethnic Livnovian militia are known as 'Armed Forces of East Livnovia' (LOAF). The NATO Task Force, with the UK acting as the lead nation, is a Division-sized force with a task of disarming the LOAF. NATO forces have undertaken to escort all aid convoys.

The broader NATO mission is to restore peace and stability to the area in order to create the conditions for a free vote by the population on the future of the region.

Current Situation

Current Rules of Engagement are P2 D2, I1

ROE State	Meaning
P2	Personal wpns may be used to engage a positively identified threat.
D2	Direct fire wpns may be used to engage a positively identified threat.
I1	Indirect fire systems up to and inclusive of 105mm may be used to engage a positively identified threat in counter fire or in response to a formal order from a Bde (or eqv) FDC.

Update: At 1530 hours

Call-sign A21 consisting of a section with two land rovers (LR) escorting a civilian relief convoy of six vehicles has been stopped at a probable Illegal Vehicle Control Point (IVCP) in the Nettoyer Pass. The IVCP consist of twelve men, armed with AK-47 assault rifles and at least 2 RPG-7's. The second escort Land Rover is 500m to the east of the convoy.

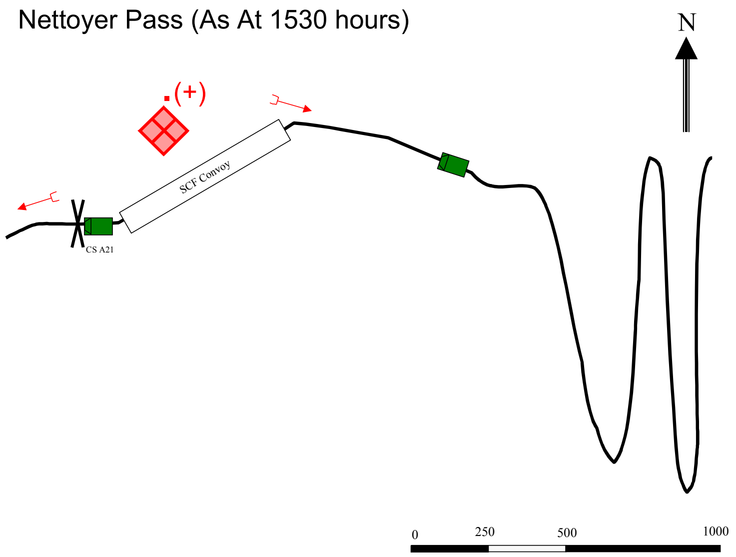


Figure 4: Peace support scenario situation update

The subjects' responses varied across a wide range of courses of action: deploy quick reaction force, prepare quick reaction force, find out what they want, try to negotiate and do **not** deploy quick reaction force, etc.

Experimental Results

In both scenarios there is a broad range of CoAs across the twenty-four participants. The participants are referred to by letter (from A to X). Their responses are depicted below in Figures 5 and 6 for the two scenarios. Where the situation is unclear, a CoA may have been chosen conditional on the use of recce (depicted by an arrow to the appropriate

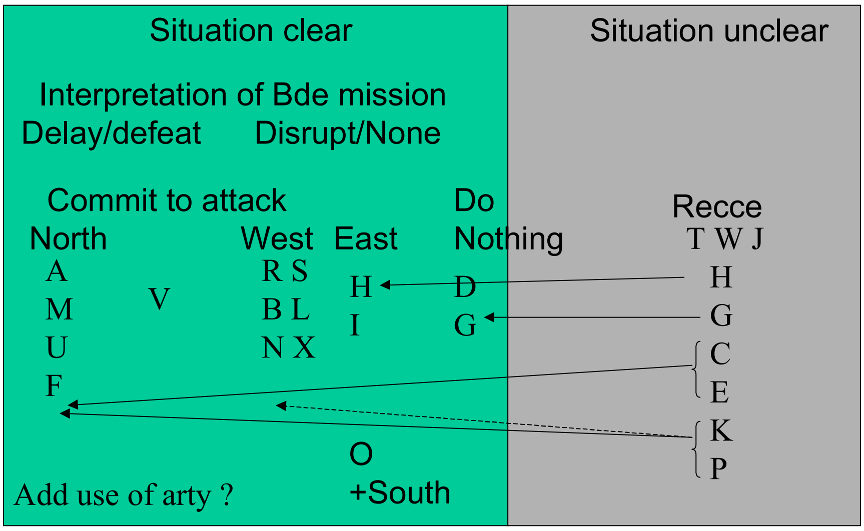


Figure 5: CoA Responses for warfighting scenario for all 24 participants

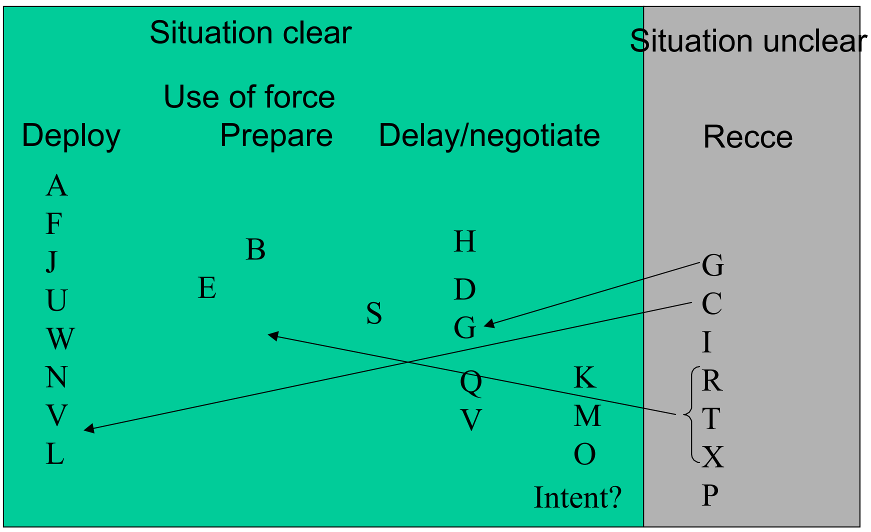


Figure 6: CoA Responses for Peace Support scenario for all 24 participants

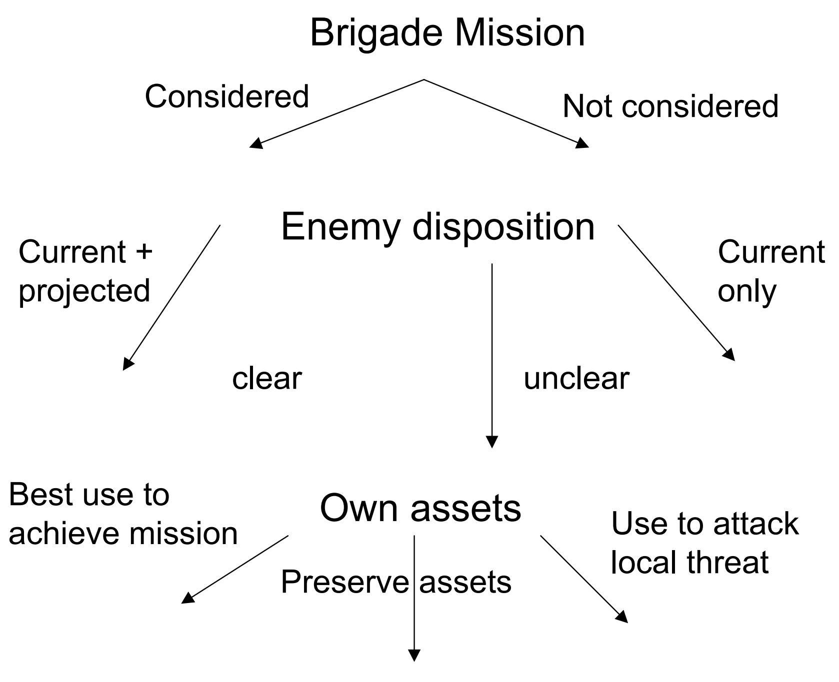
Analysis of Results

Initial analysis of the RPD responses shows that the CoA selection is driven by the extent to which the participants consider:

- Brigade Intent and mission
- Enemy disposition and intent
- Own force strengths and assets
- Projections of potential outcomes.

Also there is a clear division in the responses according to whether or not the participants are clear or unclear about the situation.

The following tree structure appears to determine the route through the pattern-matching process to show, for the warfighting scenario, how the participants split into CoA response categories:



The decision tree for the pattern-matching process for the peace support scenario is similar in structure. The main splitting factor is the extent to which the participant considers enemy intent which ranges across destruction of convoy, armed theft of supplies, precursor to ambush, nuisance factor, deliberate provocation, etc. Equally interesting is the grouping of responses according to personality type and experience. This analysis is still on-going.

Subjective Analysis

Certain participants have been selected for further subjective analysis. The subjective analysis involves post-rationalisation of the decisions but it is interesting and useful to establish whether valuation of utility/loss is feasible. It is also useful to explore any significance of situation projection in determination of CoA. The non-linear utility theory assumes that any belief universe can be formally described in terms of a triple (U,D,X) of Utility-values, Decision-space and Beliefs. Such triples may drive the CoA decision but should be evaluated and analysed within the context of the triples pertaining to the command levels immediately above and below that of the decision-maker (or least to the best of their interpretation and understanding). For the BG experiment the triples for the three command levels would typically be:

- Battle Group:
  - U is an overall co-ordinated military outcome whose success will be measured according to the extent of achievement in the BG mission areas (for example, losses, co-ordination of forces, tactical effectiveness, etc). U can be dynamic, needing to respond to changing objectives, influenced for example by changing higher-level directives.
  - D is the mission space (constrained by the specific meanings embodied within the mission verbs) physical terrain, own force assets, enemy disposition and relative strengths and the interpretation of RoEs.
  - X is based on Intelligence information and assessments and reports from the ground, so this is also dynamic.
- Brigade:
  - U is a set of Effects-based measures valued according to the changing political and operational environments.
  - D is determined by protocols and availability of resources; e.g. personnel & support packages and is not so dynamic.
  - X is based on planning projections based on experience, Intelligence and wargaming as part of the Estimate process.
- Company:
  - U is defined in terms of the interpretation of command orders from the tactical commander on the ground (i.e. putting priority values on all aspects of the tactical mission); it is also moderated by an understanding of the moral states of the fighting units.
  - D consists of the tactical constraints (typically local terrain, equipment, combat readiness and effectiveness etc) on the tactical CoA he wishes to employ.
  - X is defined by the certainty, provenance and currency of the information he has and the nature of the tactical situation he finds himself in.

Specific subjects were selected from the experiment participants because of interesting differences in their background experience and because they selected very different CoAs. Work on the subjective analysis is still on-going.

Conclusions and Recommendations

The Rapid Planning process, based on a Bayesian Dynamic linear Model, is the foundation for our current Command Agent models. This pattern-matching process follows the principles of Klein's Recognition-Primed Decision-making but algorithmic and fixed assumptions are made about the configuration of the patterns. The aim of the research into non-linear utility theory is to explore quantitative ways of extend the Rapid Planning process that capture the subjective nature of the pattern-matching process.

The results of the RPD experimental game show that different levels of expertise and personal history take decision-makers along different paths in the pattern-matching process. Consequently there is a large degree of variability in the selected courses of action across the twenty-four participants in the experiment. It is these subjective differences in the pattern-matching process that must be captured in the Command Agent models. The paths taken in the pattern-matching process could be described formally if it were possible to quantify the (U,D,X) triples for the decision-maker. The triple would define a decision landscape within which the pattern-matching process could be modeled using the Rapid Planning process. The only way to establish the values for the triples is to ask participants to post-rationalise their decisions as outlined in the subjective analysis description.

The paper recommends that the results of the subjective analyses be explored as a means of extending the Rapid Planning process to allow for the differing strategies in the pattern-matching process. Non-linear utility theory offers a formal method for defining the constraints, subjective function and projection mechanism of a descriptive, complex optimisation algorithm for the determination of course of action by a Command Agent model. The challenge lies in bringing together the naturalistic and human aspects of RPD pattern-matching and the quantitative aspects of subjective utility theory.

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[10] *Paper in preparation for submission to JORS*

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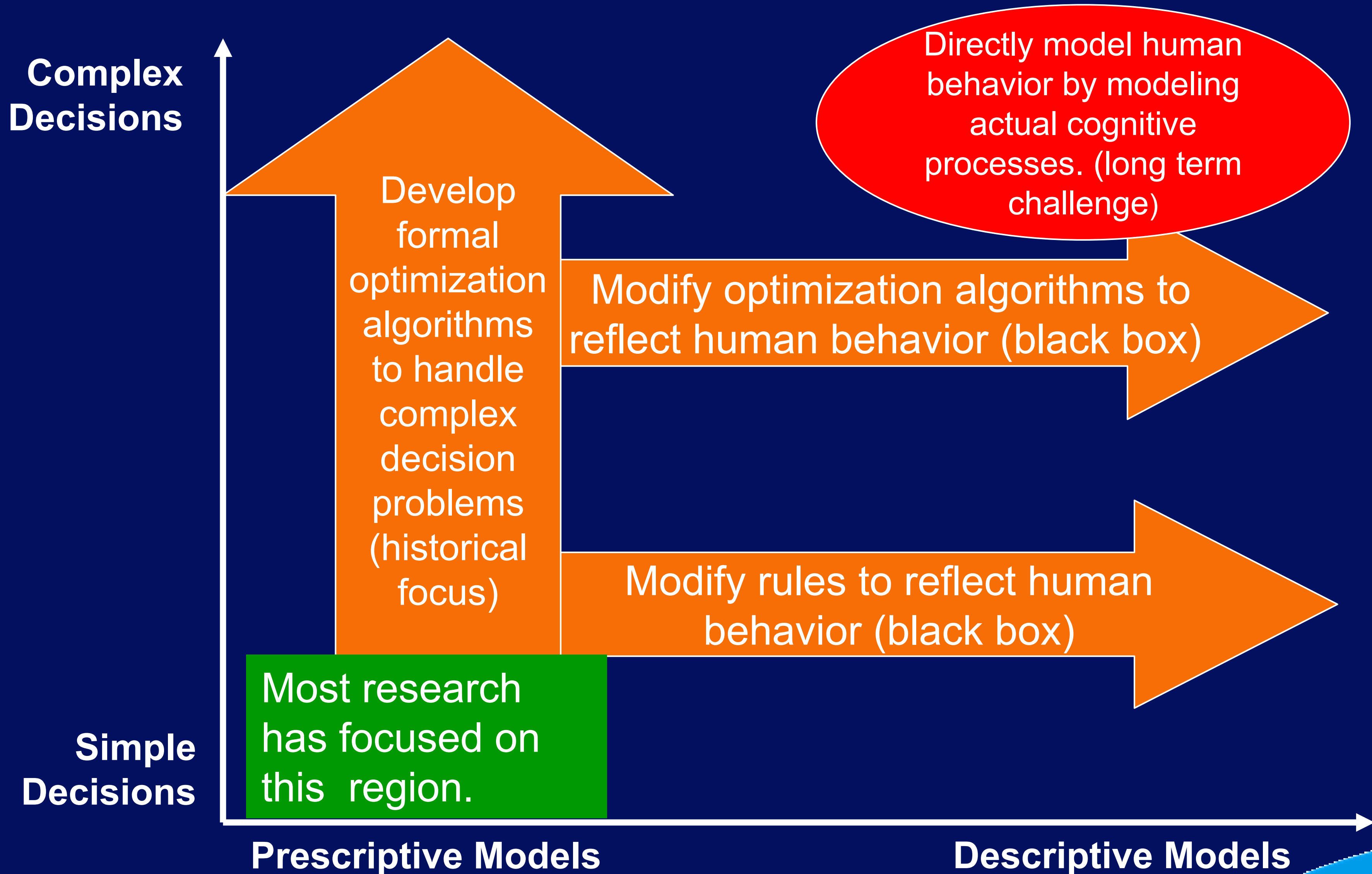
Strategies for Improved Models



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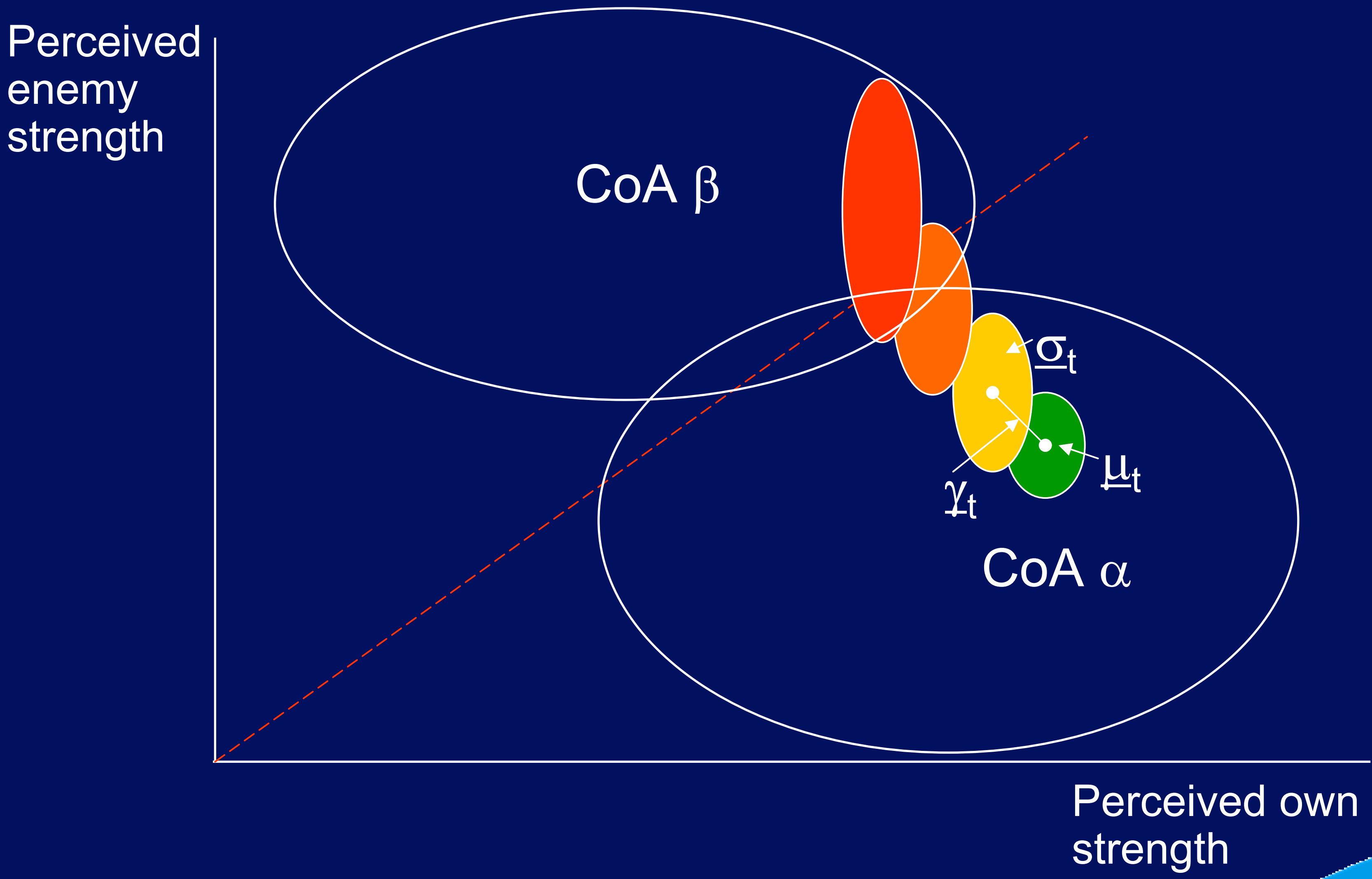
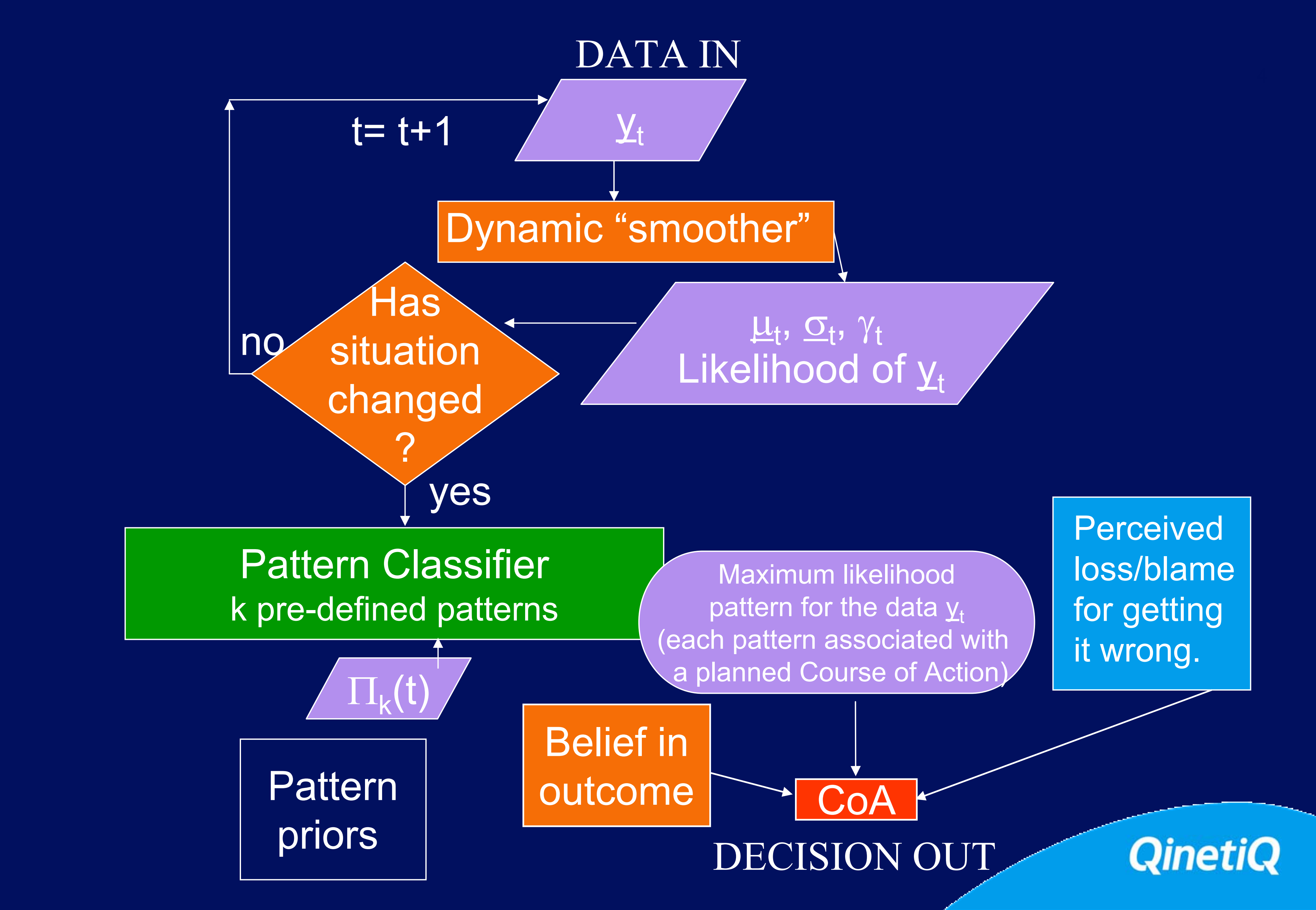
Configuration Space - Klein Pattern Matching Course of Action selection




DATA IN
$\underline{y}_t$
t= t+1
Dynamic "smoother"
Has situation changed ?
no
$\underline{\mu}_t$, $\underline{\sigma}_t$, γ_t
Likelihood of $\underline{y}_t$
yes
Pattern Classifier
k pre-defined patterns
Maximum likelihood pattern for the data $\underline{y}_t$ (each pattern associated with a planned Course of Action)
Perceived loss/blame for getting it wrong.
$\Pi_k(t)$
Pattern priors
Belief in outcome
CoA
DECISION OUT
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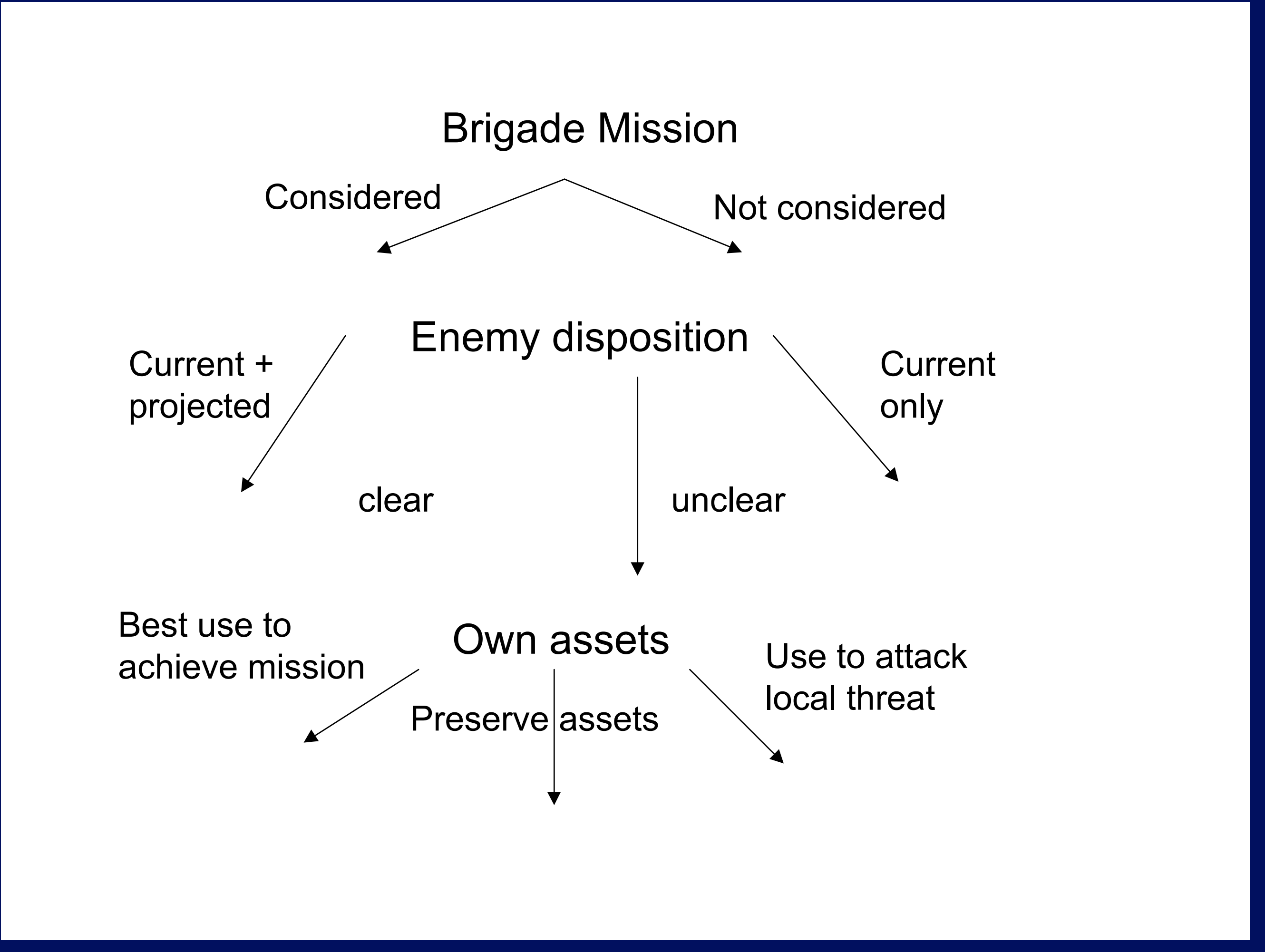
RPD experimental games

Command decision-making experiments to explain variability in decision output due to human element: 24 subjects

- War-fighting scenario
  - Battle-group command decision for an armoured (3,0) BG in a delay/disrupt mission.
- Peace-support scenario
  - similar level of command but decision concerning small armed units protecting a UN convoy

Routes through Situation Assessment



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Klum
1 LI
B
1 LI
Probable LOAF
LAF
Livnovia
A
1 LI
I(-)
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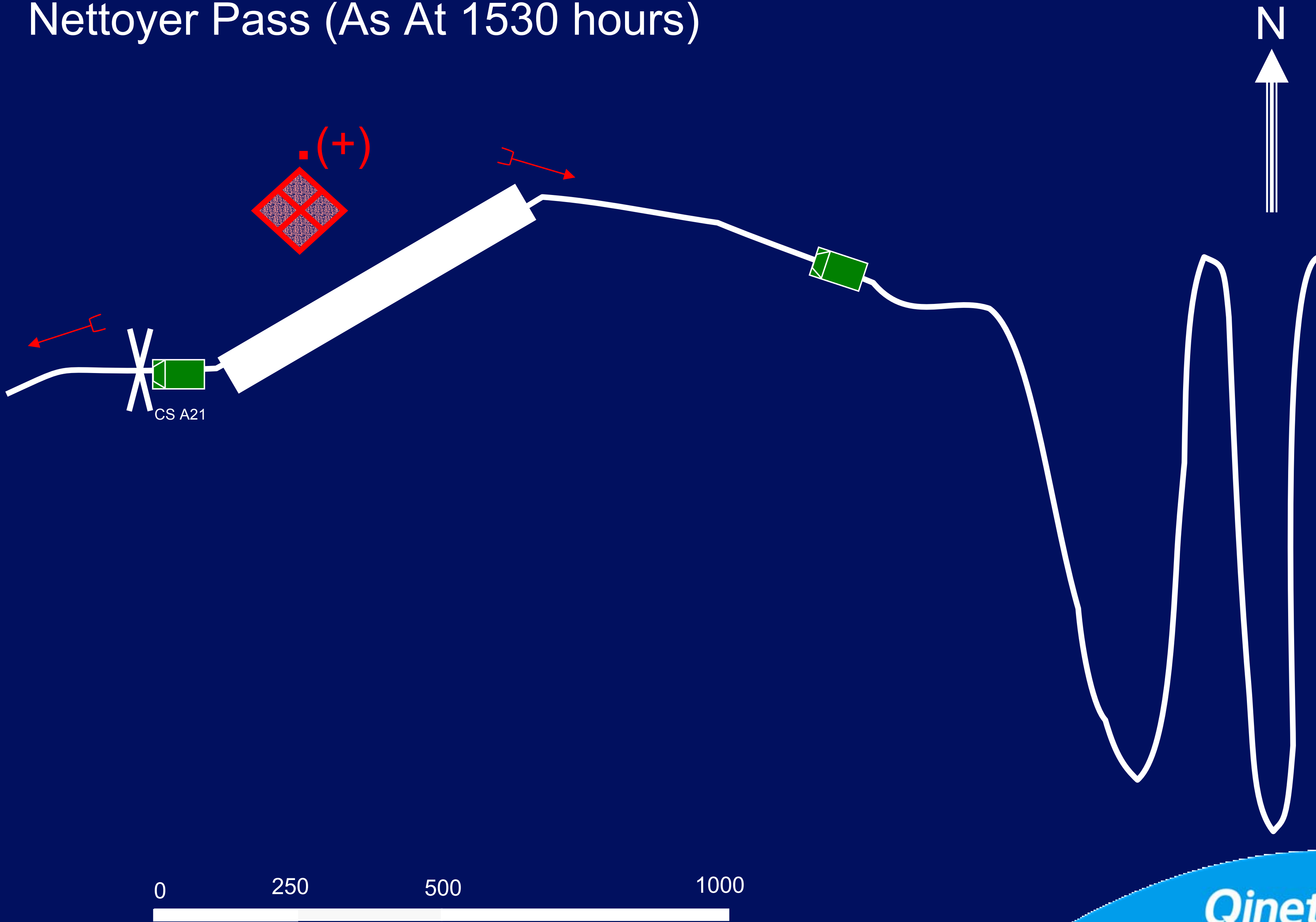
Nettoyer Pass (As At 1530 hours)



Situation assessments

- Show of presence
- Provocation
- Theft of kit/convoy supplies
- Kidnap hostages
- All the above are possibilities
- Ambush set-up by LOAF

Selected courses of action

- Negotiate
- Ask for more information - what IVCP want
- Prepare Coy forces (move arty into range)
- Deploy QRF
- Withdraw convoy
- Defensive deployment / target LOAF

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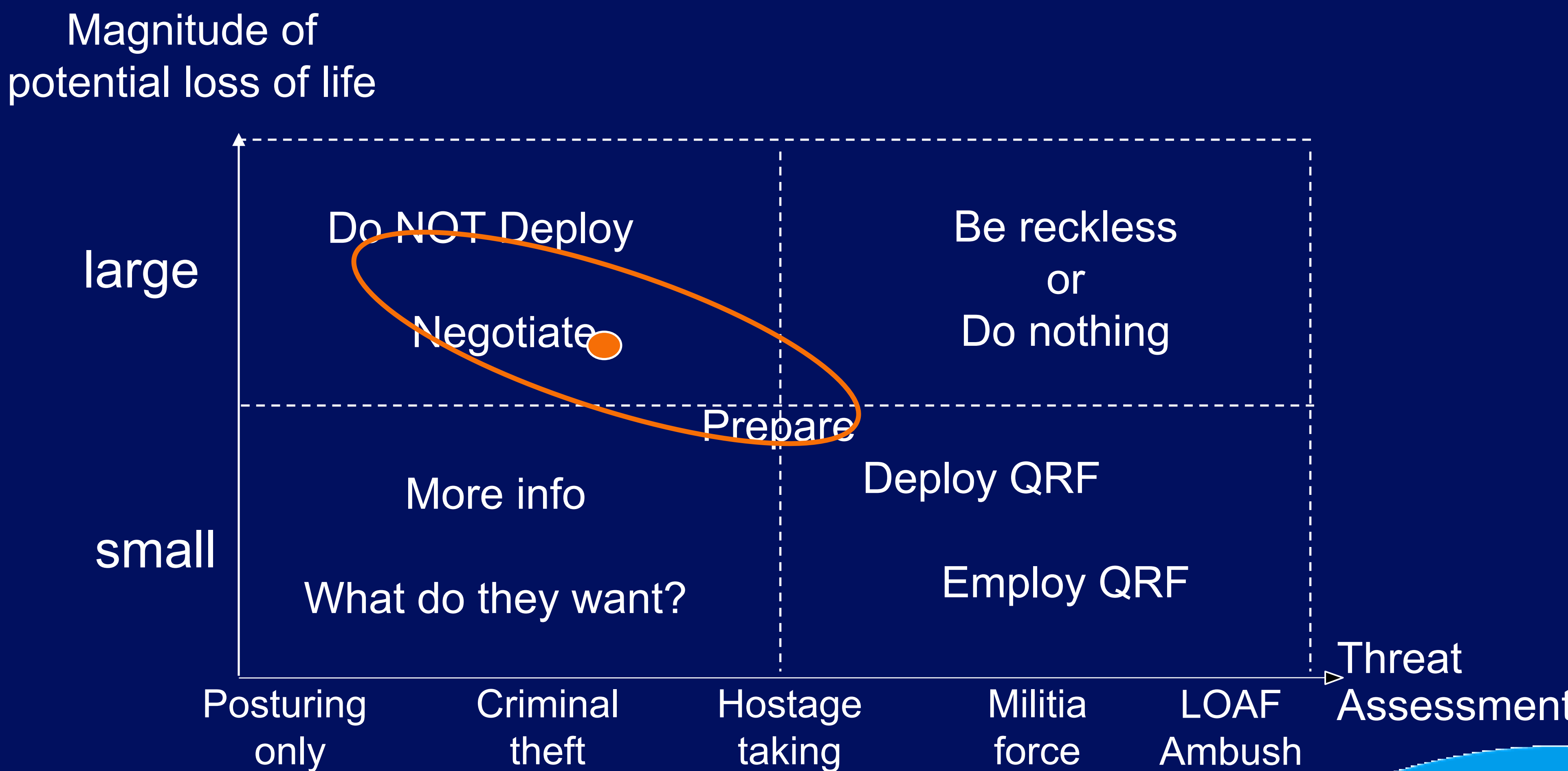
Situation Assessment: Simplified State Space



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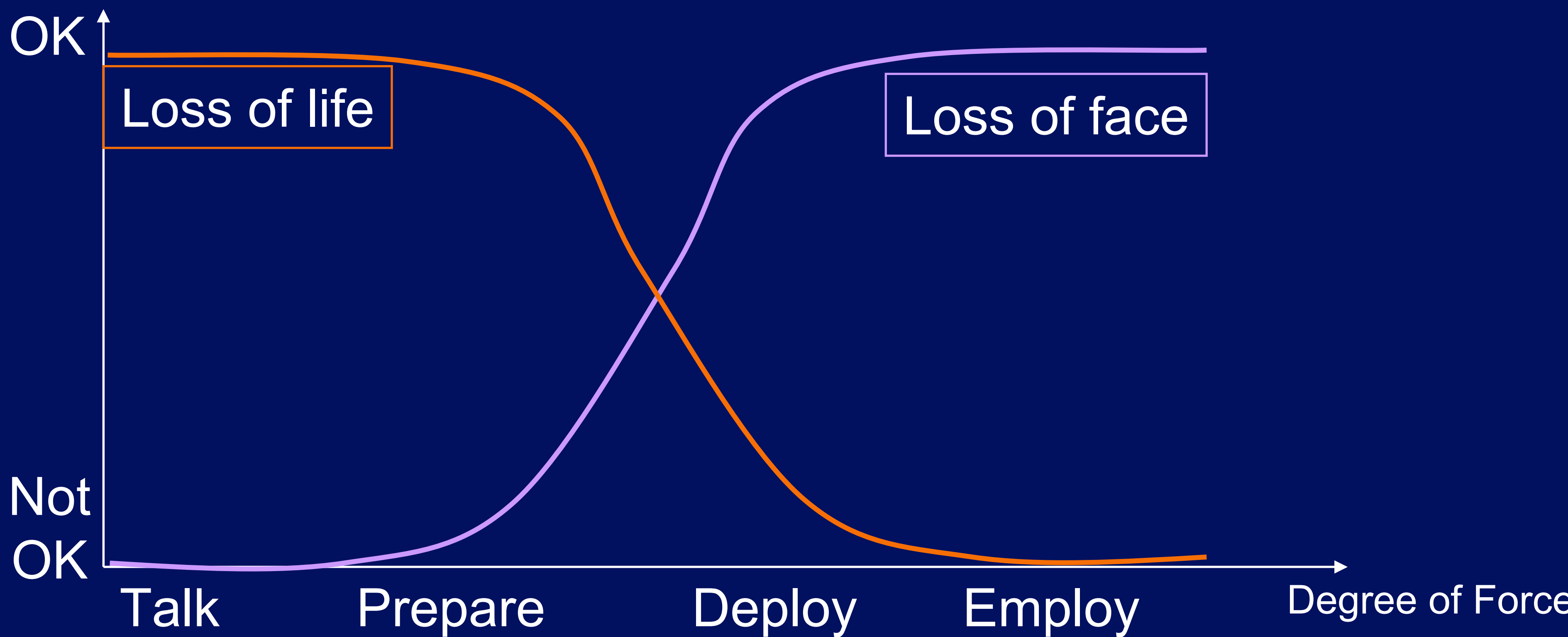
Ok/not-OK value judgement



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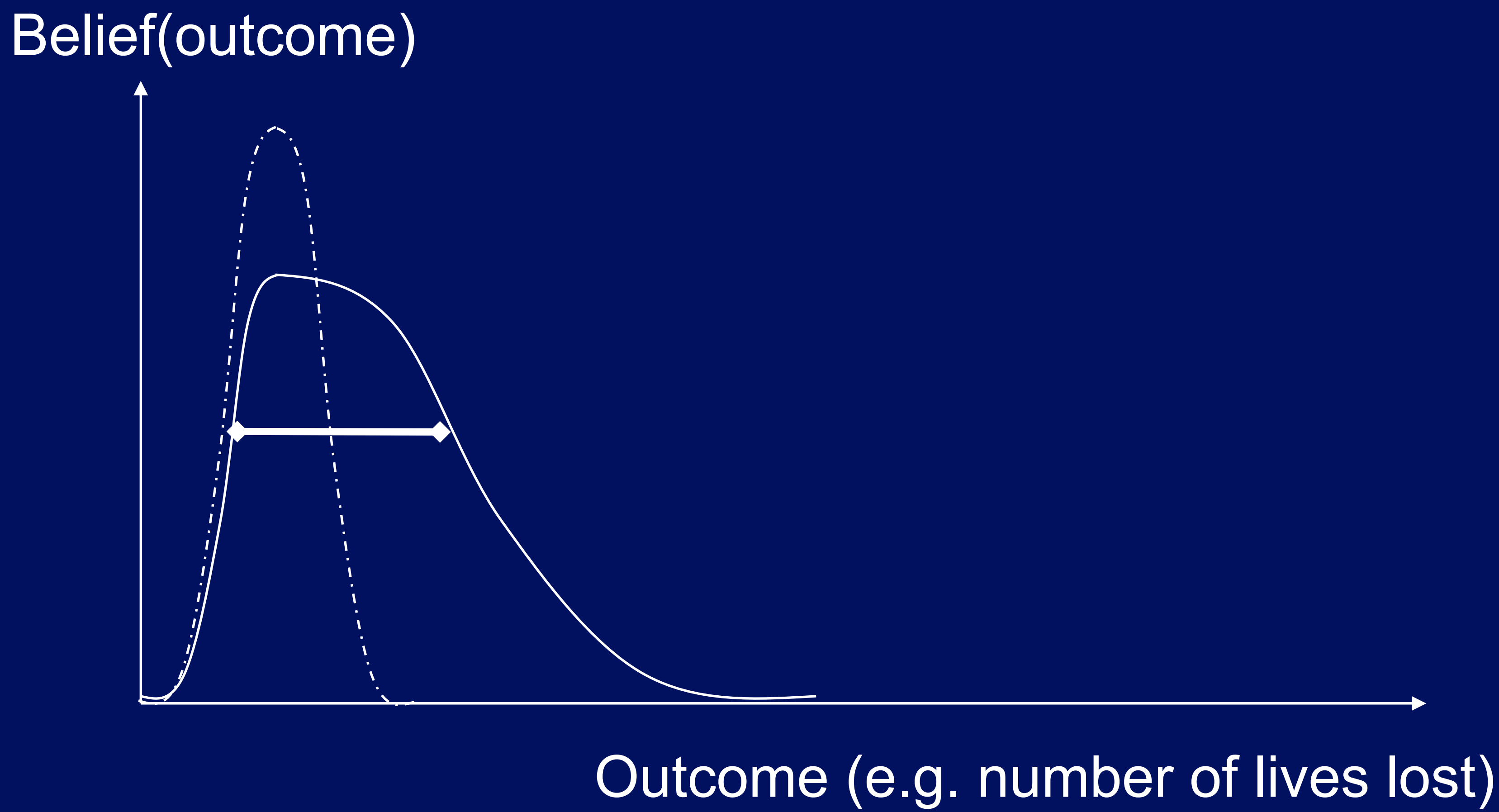
Predictability of outcome



Threat Assessment and Risk Assessment

Previous mathematical model combined TA and RA to minimise expected loss and showed that when there are conflicting local and global OK functions the decision space has two minima.

If the functions can be brought closer together then the two minima converge to give one "best" CoA. Otherwise the decision flips between the two according to:

- movement through the threat assessment space
- movement in the comfort zone boundaries

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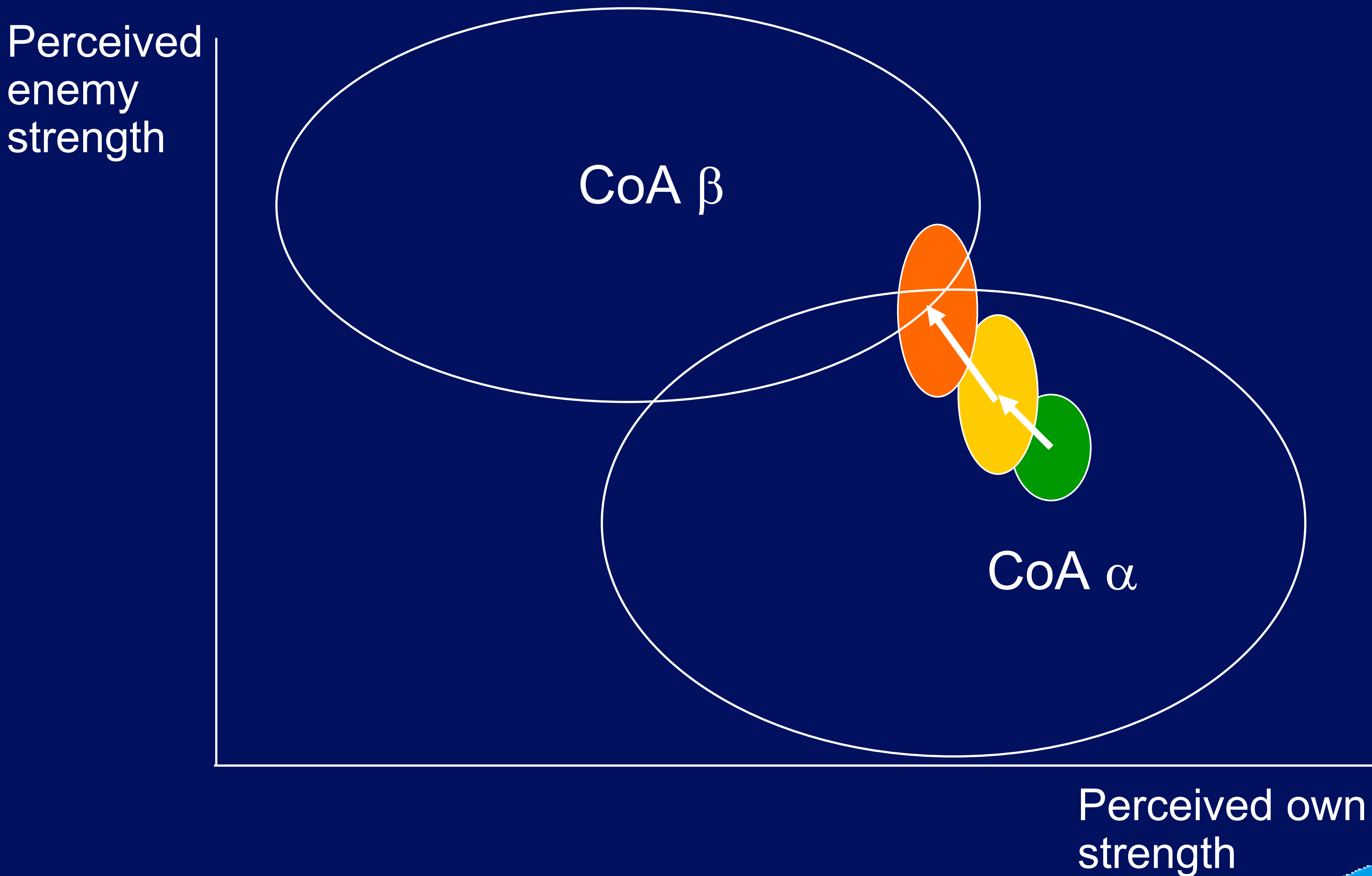
Changing situation assessment has effect on Course of Action selection



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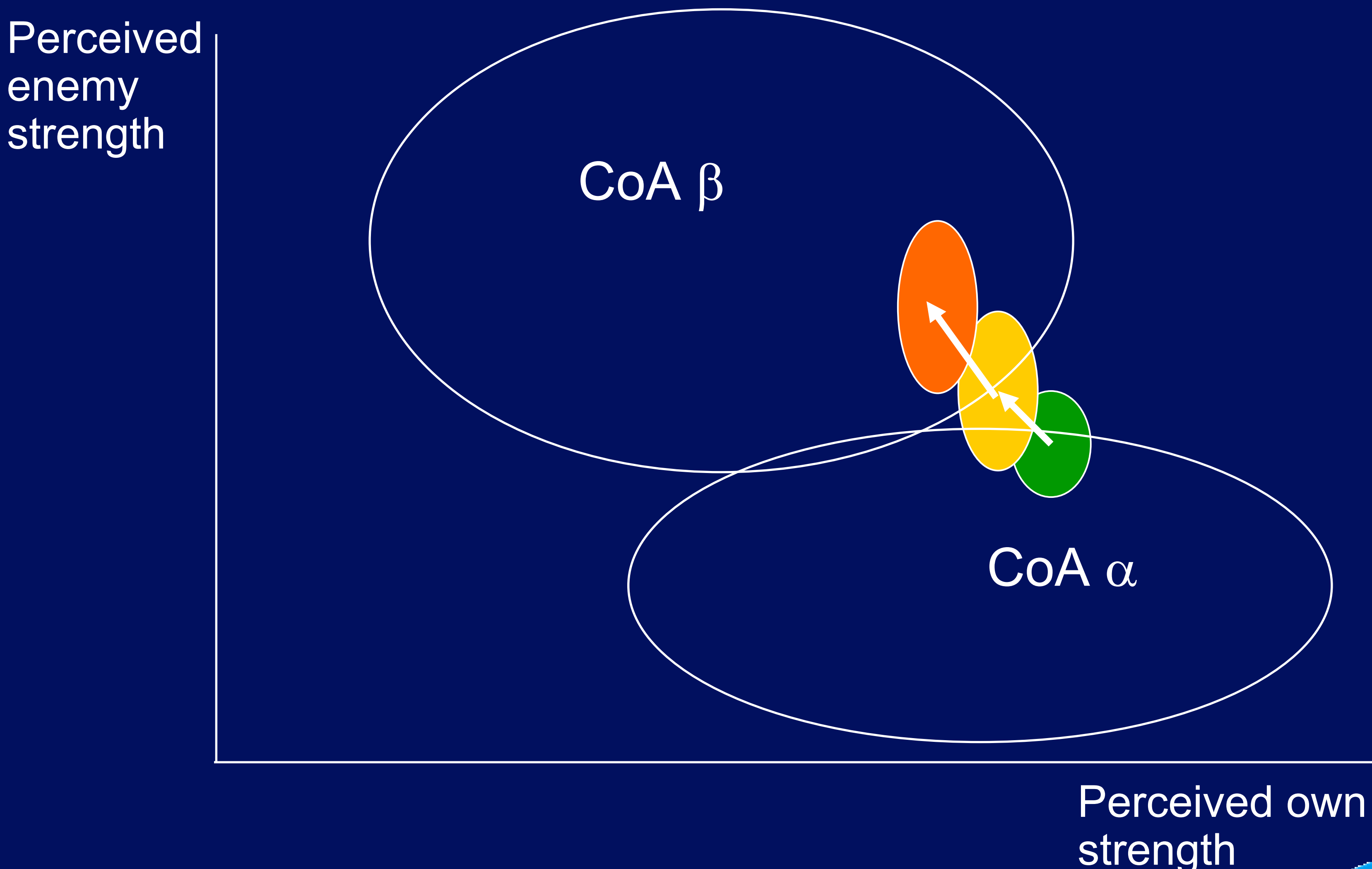
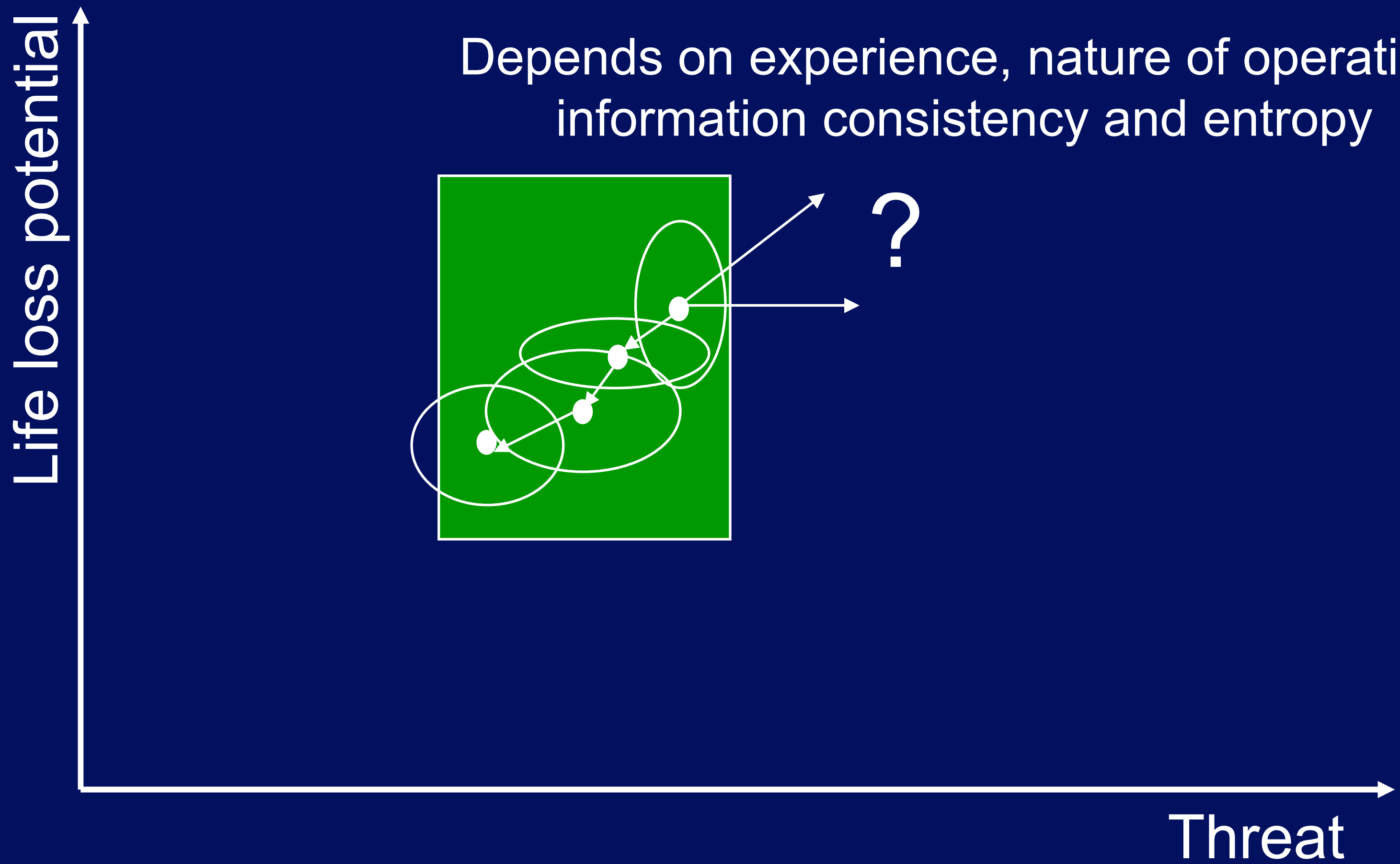
Changing position of comfort zones has effect on Course of Action selection



Belief, predictability and precision



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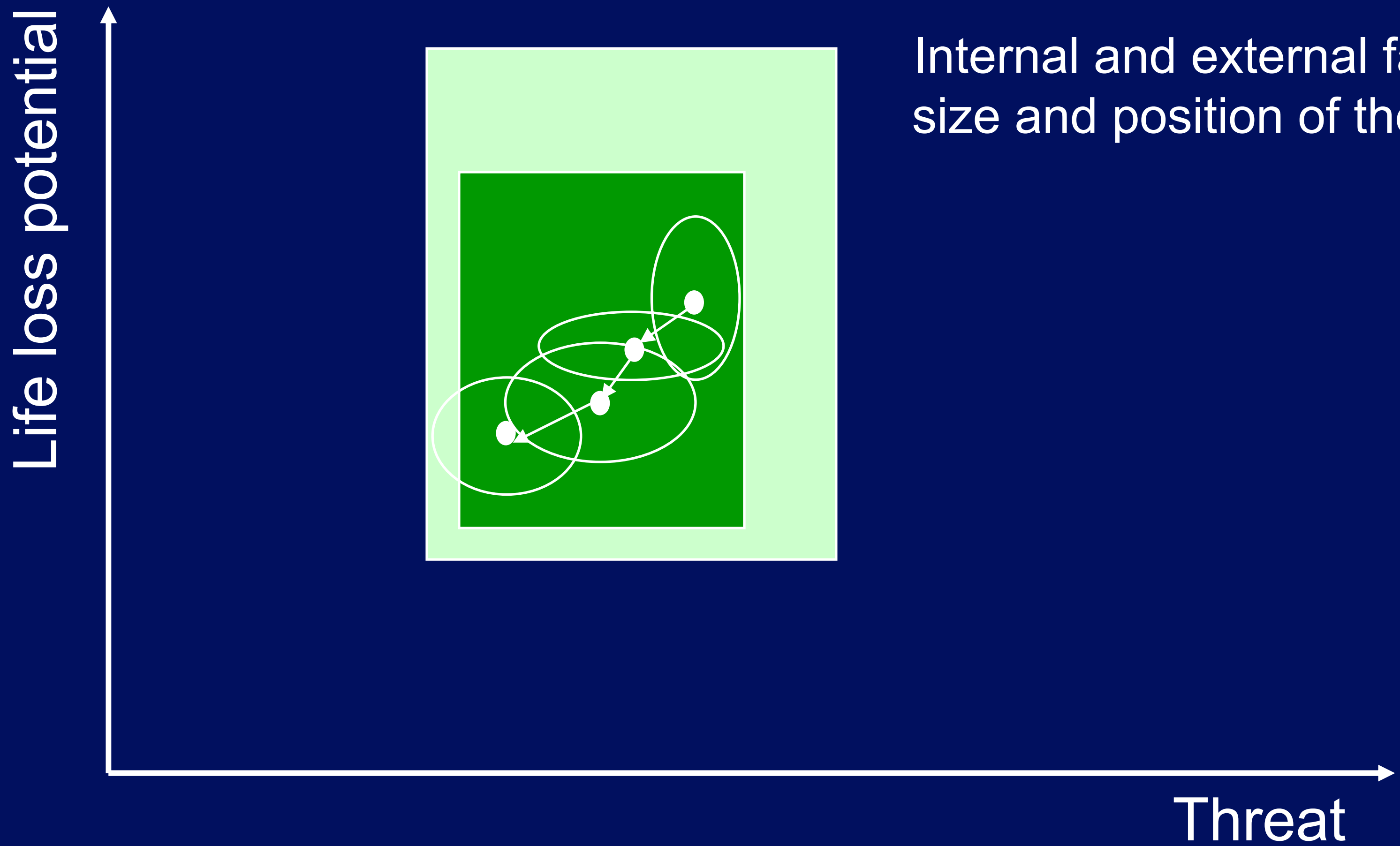
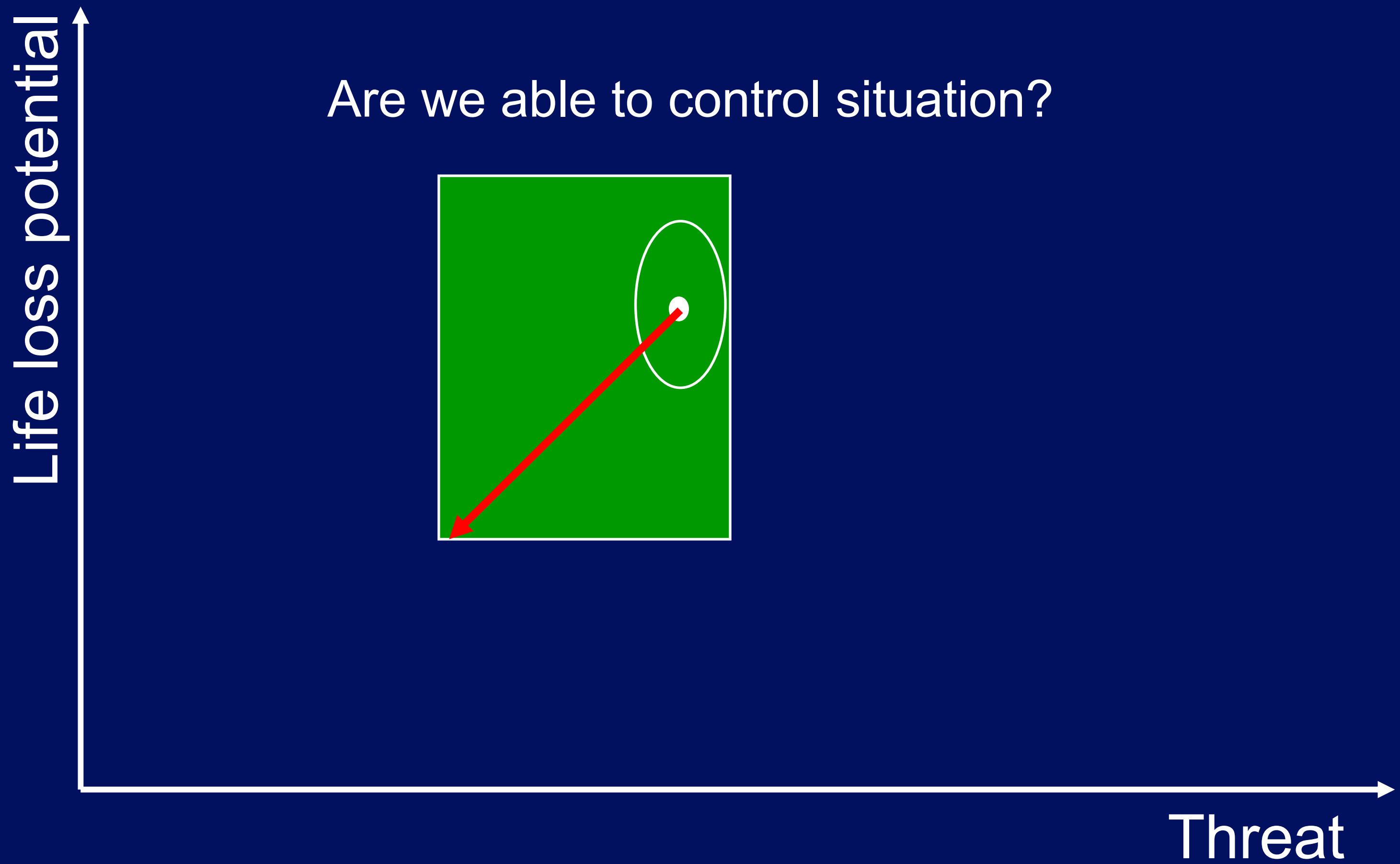
Local versus Global Criticality



Internal and external factors change size and position of the comfort zone

Controllability



Conclusions open to debate and more study

- Experience and training tend to affect the subject's position in situation state-space
- Personality and personal values seem to affect the comfort zone boundaries and global factors also move the boundaries
- Information is a bias factor on the position in situation-space and entropy affects projection and ability to be precise
- C2 network structures affect controllability
- Creative CoA generation is enhanced control

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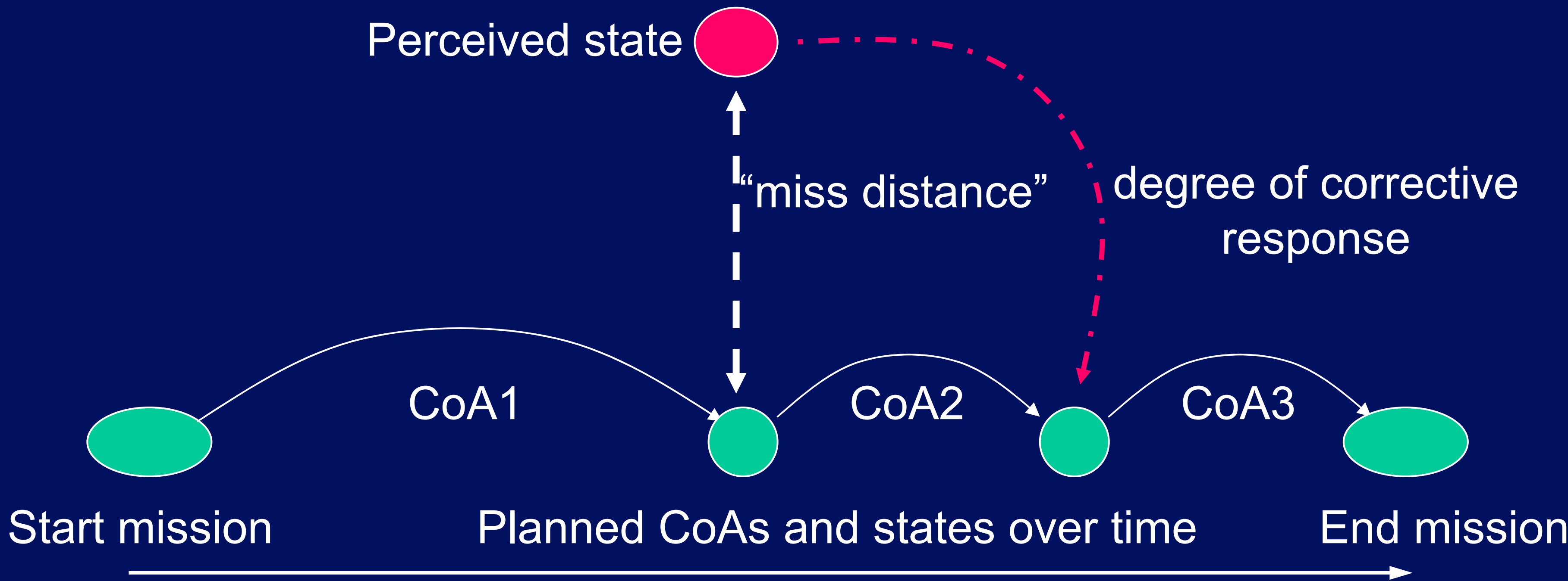
Assumptions

- Situation Assessment and Course of Action generation / selection are inextricably tied; classification of the perceived situation creates the feasible set of Courses of Action
- For a bounded operational setting, a ‘state’ (generic class of situation) can be defined on a small set of state variables
- The envelope of expected states can be represented by a state transition network; each transition represents a high-level Course of Action
- The domain under consideration is land tactical conflict

CoA Selection: State Transitions



- Clarity/sentience of desired mission aim or end-state
- Interpretation of current situation/ enemy intent
- Is corrective action feasible given time and resources?
- If so, what are potential consequences of action?
- Should I carry out action, more recce or change plan?

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Risk Assessments

- War-fighting
  - casualties
  - ability to be effective with tanks against infantry
  - success of Bde mission
  - own life threatened and that of own units
- peace support
  - civilian casualties / hostages
  - theft of weapons and supplies
  - time pressure

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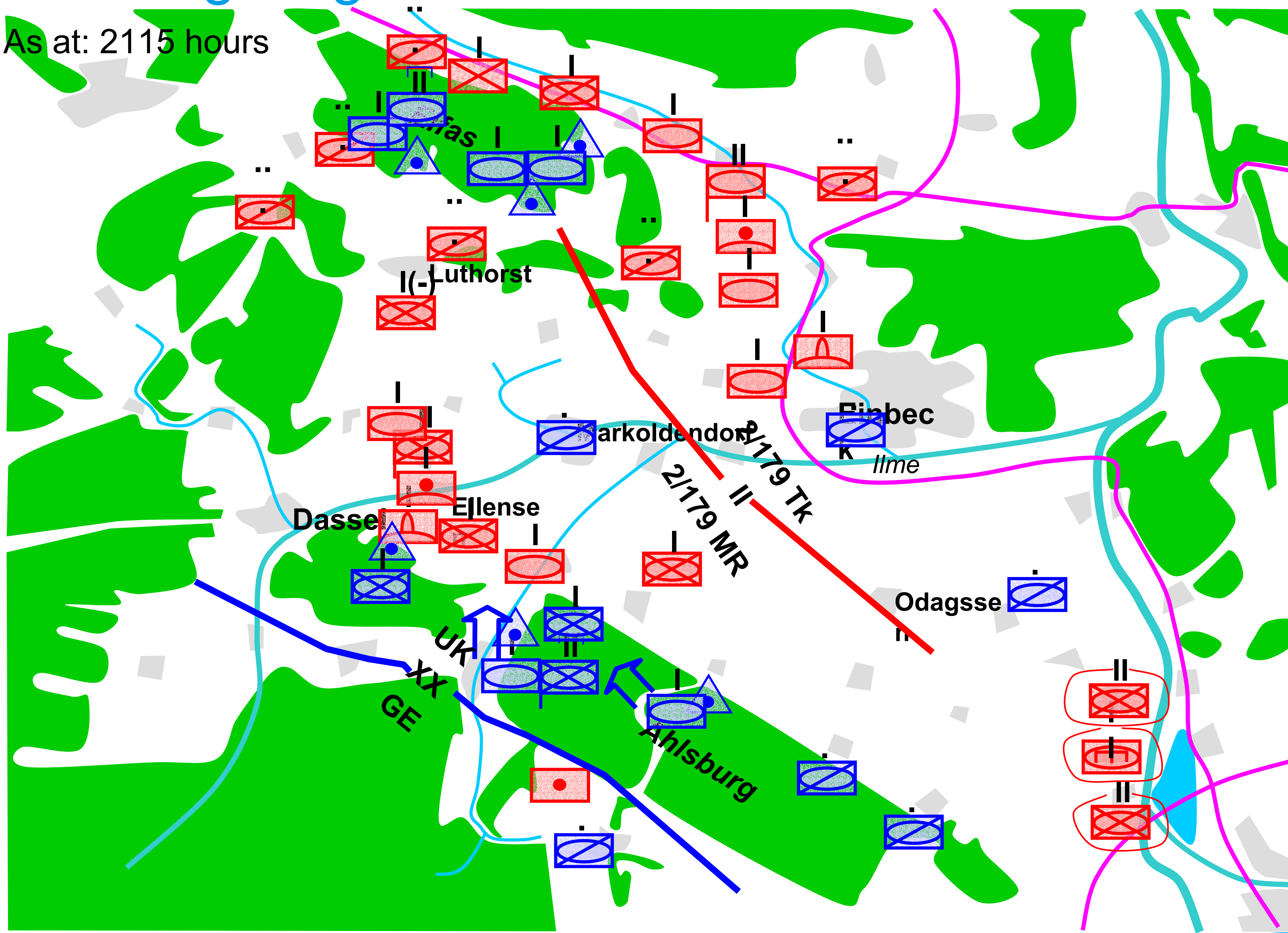
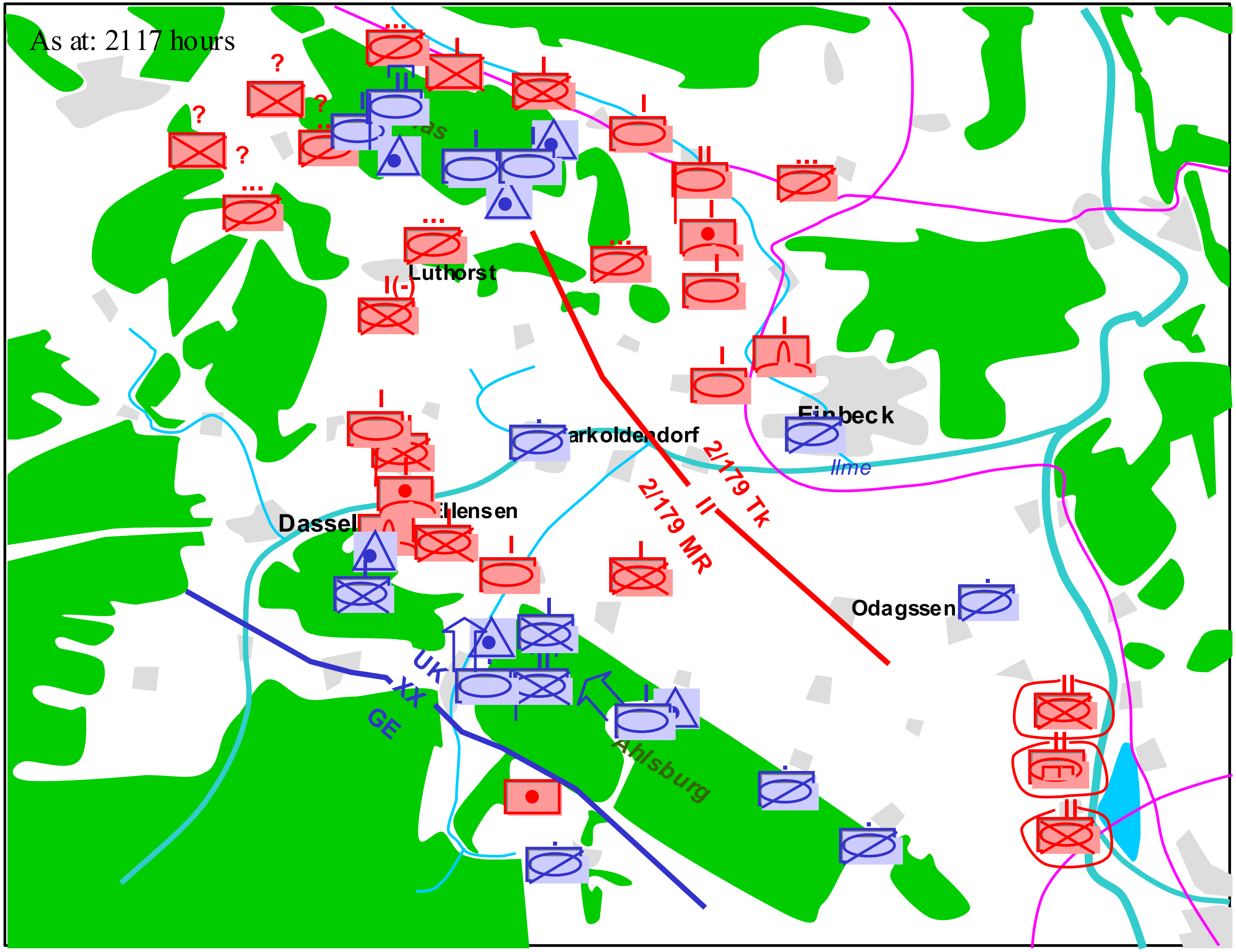
War-fighting scenario

As at: 2115 hours



War-fighting scenario



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Situation assessments

- Enemy committing to axis/axes
- Enemy link-up to secure gap
- Enemy by-passing/leapfrogging my position
- Enemy blocking to isolate/fix me
- Encirclement/envelopment of my position
- Unclear on axis - could be feint

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Selected courses of action

- Attack armoured units to North
- Attack descant units in West
- Use of Arty to support/prepare attacks
- Move East to secure safe route out
- Stay in hides and do nothing
- Request information and more recce
- (Report situation and defer to Brigade)